Harbor Threat Detection, Classification, and Identification

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LONG-TERM GOALS

There is a critical need for reliably and rapidly detecting, identifying, and tracking submerged low observable targets in port environments, which would allow for rapid and effective neutralization of low observable threats. Without this capability, personnel, naval platforms and targets of opportunity are exposed to a cheap kill by an opportunistic threat. The long term goal of this effort is to exploit for the first time detailed active and passive signature information of harbor threats together with advanced Bayesian classifier techniques. Ultimately it is the intent of this effort to leverage the highly successful science and technology carried out in broadband mine identification [1] and EOY reports for Award Numbers: N0001406WX20052 and N0001406WX20679].

OBJECTIVES

The objective is to exploit passive and active acoustic signal information associated with submerged threats in harbors and ports in order to monitor their presence in real time. There is no known capability for reliably detecting, identifying, and tracking low observable targets in such environments, particularly at ranges ~ 1km. Submerged threats include a variety of both man-made and human targets and this project emphasizes swimmer and non-swimmer threats. This project will lead to identification and demonstration through experimentation and simulation.

APPROACH

The acoustic work is broken into the following areas. The first involves comprehensive, highly controlled broadband, multi-aspect measurements of swimmer related acoustic signals (both passively generated and in response to active acoustic insonification).   The second area involves the development of suitable signal processing techniques including both tracking and identification

algorithms that can operate effectively on the environmentally corrupted threat target signals. These include, among others, those based on kernel matching pursuits, relevance vector machines [2-5], and time reversal mirrors recently developed at NRL [6,7]. The studies include the full range of broadband frequencies. The spectrum is limited at the extremes for practical deployment purposes but the frequency range are sufficiently broad enough to capitalize on potential discoveries of target/false target signal features useful for identification.
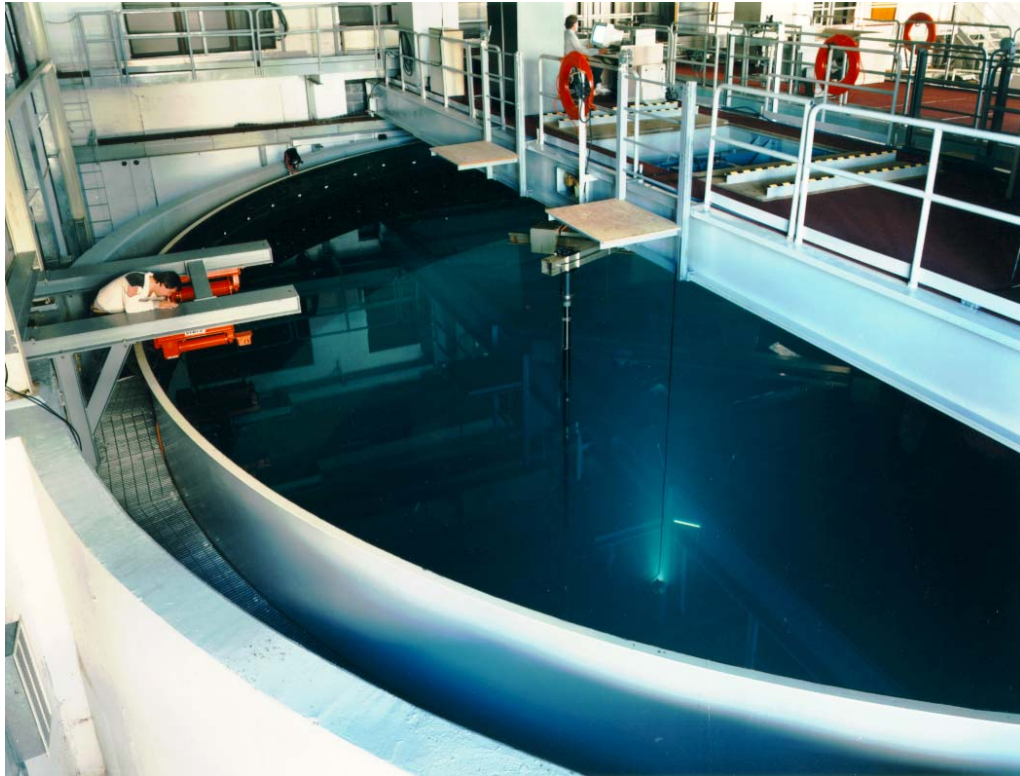

Fig. 1 — The Large Acoustic Tank at NRL used to acquire the broadband active and passive signature data.
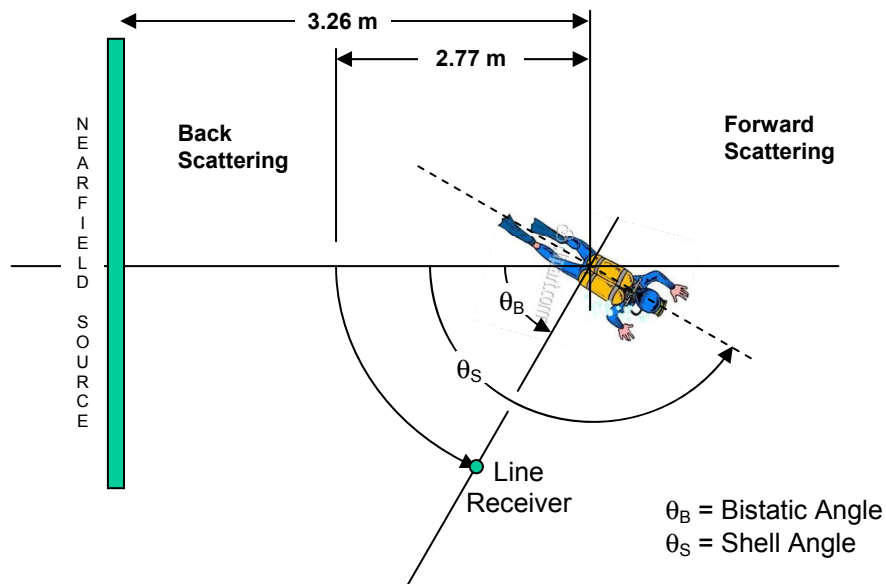
***Fig. 2 — The measurement range used in the NRL laboratory measurements. Both
radiated noise and broadband active measurements were carried taken. For the active
measurements, a horizontally oriented line array is used as a source.***

The approach involves two tasks.

Task 1: Database Generation: NRL will provide measurements and analysis of additional signature
threats by using its Laboratory for Structural Acoustics at NRL. The priority of signature
measurements is (1) diver with commercial rebreathers, (2) diver with diver assisted propulsors, and
(3) small UUVs. The measurement band is (1 – 200 kHz) and the angular resolution of the diver
rotation is 5 degrees. Note that the system resolution is much higher (i.e. 1/10,000 of a degree), and
the 5 degree resolution associated with diver measurements is due to the practical issue of dealing with
having a human test subject.

Task 2: Detection, Tracking and Identification: NRL and SIG will carry out an Evaluation of the
application of advanced MCM Related Techniques to the Diver Detection Problem. The overall
approach centers on examining existing databases generated with conventional harbor protection
sonars and the new data acquired in Task 1. The intent is to apply highly successful techniques
developed for the Low Frequency Broadband mine program (LFBB) (ONR - Dr. K. Commander) to
the detection, tracking, and identification phases of the diver related problem.

WORK COMPLETED

In Task 1, NRL carried out broadband measurements of two commercial rebreather units. The so-
called Optima and the Inspiration units are two of the most popular commercially available diver
rebreather units. NRL used its facilities to carry out broadband target scattering and radiation
measurements on these two devices (worn by a diver). NRL also completed measurements on diver
assisted propulsors. With regards to NRL's overall database, NRL now has broadband data on
conventional scuba systems, the MK16, the Optima, and the Inspiration rebreathers.

In Task 2, we were successful in examining the ability of the acoustic scattering response to be used to separate divers from potential clutter. Since no significant clutter is yet available, scattering from divers using both open and closed systems has been analyzed and used to demonstrate an ability to identify individual divers from each other and, by inference, clutter. The identification is based solely on the structural acoustic response of the diver, and it is not, at this stage, aided by the tracking information that is exploited by operational systems. This work was preformed using the free field scattering data collected in the NRL laboratory facility under Task 1. In addition to this analysis of the structural acoustic responses from laboratory data, the team carried analysis of data collected by the AN/WQX-2 sonar at Lake Travis, Texas. First, we examined the narrowband AN/WQX-2 data to explore the possibility that target scattering derived features might be useful in improving the existing classifier. For this, structural acoustic analysis precludes solely using the feature vectors extracted via the APL-UT feature extractor and readily available. Thus, NRL carried out a significant effort to deconvolve base-banded data generate by the AN/WQX-2 so that scattering-based features could be examined. Second, SIG developed a particle-filter tracking algorithm based on the time-evolving feature data and carried out careful analysis of the statistical properties of the features extracted from the acoustic-scattering data.

RESULTS

Since a single collection of monostatic scattering angles spaced 5 degrees apart encircling the diver was collected for each type of diver, every other angle was used for training and the remaining angles were used for testing. As an example, the results for separating divers using structural acoustics-based features for closed systems (MK16, optima, and inspiration) from a diver using open SCUBA is shown in Figure 3. The examination of the seperability of the two types of systems is useful in the absence of real clutter data. The results show that the structural acoustic features associated with diver scattering cross-section can be distinguished from each other and that exploiting multiple pings produces a marked improvement in the performance. Absolute system performance should not be inferred from these results because many factors including the variability in divers, equipment, and environment to name a few are not addressed. What can be taken away from the results is that exploitable differences in the structural acoustic signals exist and that these differences might be exploited by current operational systems or future systems that are designed to exploit them.
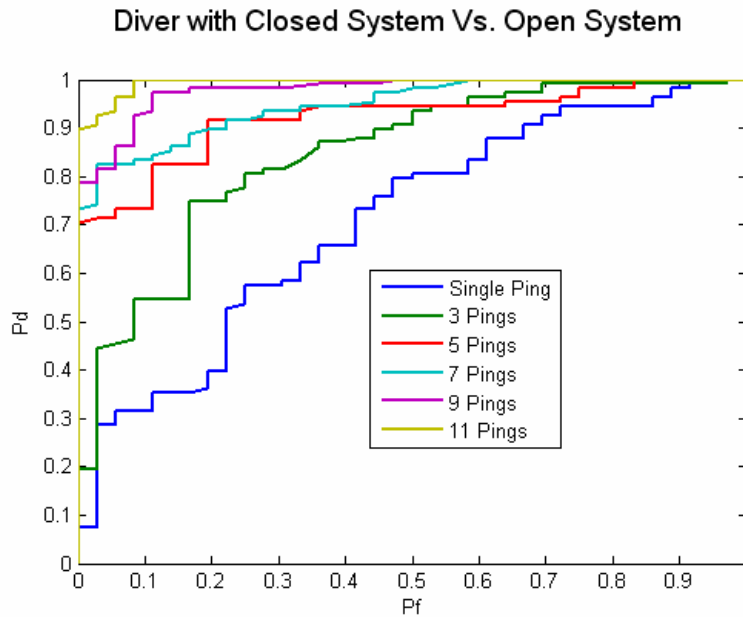
Fig. 3 — Preliminary ROC curves for the data that NRL has collected thus far. The curves below indicated the degree of separation between the closed systems and a conventional scuba.

In addition to the analysis of the structural acoustic responses from laboratory data, analysis of data collected by the AN/WQX-2 sonar at Lake Travis began during the past funding period. The structural acoustic analysis precludes solely using the feature vectors pre-extracted via the APL-UT feature extractor, which are stored on disk and readily available. The analysis to determine optimal features first requires the re-extraction of the time domain signal for each detection of interest. NRL has completed the conversion of the ARL/UT supplied data and the time domain signals have been extracted from the this data. The next phase of the research is composed of two components: 1) introducing noise and channel propagation effects into the laboratory data and optimizing the structural acoustic features for this more realistic scenario, and 2) analyzing the time domain signals from the AN/WQX-2 sonar at Lake Travis to discover the exploitable structural acoustic features.

Further, we have undertaken two additional activities during the current funding period: (i) development of particle-filter tracking algorithms based on the time-evolving feature data and (ii) careful analysis of the statistical properties of the features extracted from the acoustic-scattering data. Specifically, we are currently examining the features extracted by the APL-UT algorithm. Our focus is on understanding the statistical properties of the features, as they evolve with time, with the goal of gaining insight on the differences between clutter and target data; these insights will be exploited in improved feature design, and in subsequent detection, classification and tracker algorithms. Towards this end, we have been successful in analyzing the statistics of the features in the ARL/UT data by use of a Gaussian mixture model (GMM), we have also achieved reasonable clutter mitigation using spatial filtering, and we have also developed a tracker. Preliminary comparisons between this tracker and the ARL/UT supplied tracker results have been made. This sets the stage for the next phase of research that should include: (i) modeling and analysis of the *sequential* features via hidden Markov models (HMMs) for use in detection, tracking and classification algorithms; (ii) utilization of kernel-based classifiers such as the relevance vector machine (RVM) and kernel matching pursuits (KMP);

and (iii) exploitation of contextual information via semi-supervised learning, and (iv) and the exploitation of target scattering physics-based features.

IMPACT/APPLICATIONS

Success will enable advanced detection and identification technology against covert terrorist swimmers, and other asymmetric threats that constitute a serious problem and challenge to harbor/port security.

RELATED PROJECTS

This program is leveraging the following efforts: (1) Harbor Protection (NRL Base Effort) and (2) ONR funded efforts in Low Frequency Broadband Mine Identification (LFBB), Award Numbers: N0001406WX20052 and N0001406WX20679.

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